CLAIMS

I claim:

1. A method of determining the location of a wireless transmitting device using a movable detection station, comprising the steps of:

obtaining the signal properties of the transmitted signals of said wireless transmitting device;

acquiring and receiving the transmitted signals from said wireless transmitting device by said movable detection station;

performing signal parameter measurements at a plurality of positions of said movable detection station on the signals transmitted by said wireless transmitting device and received by said movable detection station;

determining the location and orientation of said movable detection station at each of said positions where said signal parameter measurements are performed; and

performing estimation of the location of said wireless transmitting device.

2. The method recited in claim 1 wherein said signal parameter measurements include at least one member from the group consisting of:

measurement of delay of the signal propagation, from said wireless transmitting device to said movable detection station, or a parameter(s) related to thereof, at said positions of said movable detection station where said signal parameter measurements are performed;

measurement of difference of the signal propagation delays, from said wireless transmitting device to said movable detection station, or parameters related to thereof, wherein the difference of delays is between pairs of said positions of said

movable detection station where said signal parameter measurements are performed; and

measurement of angle of arrival of the signals, or parameters related to thereof, from said wireless transmitting device, at said positions of said movable detection station where said signal parameter measurements are performed.

3. The method of claim 2 further including a step of distinguishing the individual propagation paths, and each of said measurements of the signal parameters is conducted on the earliest arrival signal propagation path that demonstrates reliable detection, among multiple signal propagation paths.

4. The method recited in claim 1 wherein said estimation of location of said wireless transmitting device further includes transforming said measured signal parameters and said determined locations and orientations of said movable detection station obtained at said plurality of positions of said movable detection station into at least one member from the group consisting of:

a TOA (time of arrival) method, transformed from a set of said signal parameters and said locations of said movable detection station obtained at least three of said positions of said movable detection station;

a TDOA (time difference of arrival) method, transformed from a set of said signal parameters and said locations of said movable detection station obtained at least three of said positions of said movable detection station;

an AOA (angle of arrival) method, transformed from a set of said signal parameters and said locations and orientations of said movable detection station obtained at least two of said positions of said movable detection station;

a time and angle of arrival method, transformed from said signal parameters and said locations and orientations of said movable detection station obtained at least one of said positions of said movable detection station; and

a time difference and angle of arrival method, transformed from said signal parameters and said locations and orientations of said movable detection station obtained at least one pair of said positions of said movable detection station.

5. The method of claim 1 further including a method of refining said estimation of the location of said wireless transmitting device by steps of:

determining the quality of the data resulted from said signal parameter measurements and said determination of the locations and orientations of said movable detection station; and

in performing said estimation of location, applying at least one member from the group consisting of:

excluding the use of the data obtained in said signal parameter measurements and said determination of location or orientation or both of said movable detection station performed at some of said positions where said quality of said data is determined to be poor; and

applying a set of weighting factors to the use of the data obtained in said signal parameter measurements and said determination of location or orientation or both of said movable detection station at said positions, where each of the set of weighting factors is a monotonically non-decreasing function of said determined quality of corresponding said data.

6. The method of claim 5 wherein the said quality of said data is based on at least one member selected from the group consisting of:

signal to interference ratio;

signal to noise ratio;

the geometry of the position of said movable detection station to obtain said data, relative to the position of said wireless transmitting device and other positions of said movable detection station to obtain the other said data, in a location estimation method of concern, or a quantitative measure thereof; and

whether or not the detected earliest arrival signal propagation path is truly line of sight (LOS) path or truly the earliest arrival propagation path, or the confidence level thereof.

7. The method of claim 6 wherein said determining whether or not the detected earliest arrival signal propagation path from a wireless transmitting device is truly LOS path or truly earliest arrival propagation path, comprises the steps of:

from said measured signal parameters, deriving the difference of propagation delays associated with a given pair of said positions of said movable detection station, wherein said propagation delay of concern is from said wireless transmitting device to said movable detection station;

from said determined locations of said movable detection station, deriving the distance between said pair of said positions of said movable detection station; and

making determination that, if said propagation delay difference (in absolute value) associated with a given pair of said positions is larger than said distance divided by speed of light associated with the same pair of said positions, then the detected

earliest arrival propagation path associated with one of said pair of positions that has longer delay is NOT truly LOS or NOT truly earliest arrival propagation path; and if the said propagation delay difference (in absolute value) associated with a given pair of said positions is not larger than said distance divided by speed of light associated with the same pair of said positions, then the detected earliest arrival propagation paths associated with said pair of positions are UNCERTAIN whether they are truly LOS or earliest arrival propagation paths, solely based on the information associated with this said pair of positions.

8. The method of claim 5 wherein said refining of the estimation of the location of said wireless transmitting device is further performed in a progressive manner while additional data of said signal parameter measurements and said determination of location or orientation or both of said movable detection station become available at same or additional said positions of said movable detection station, comprising the steps of:

when additional said data with acceptable quality becomes available, and the total number of said data is below a predetermined maximum, using said additional data together with the existing said data;

when additional said data becomes available, and the total number of said data exceeds a predetermined maximum, excluding the worst quality data among the existing and the additional data to keep the set of usable data at said maximum size;

for repeated measurements taking at a same position of said movable detection station, only keeping the best data obtained at the same said position, and eliminating worse data, regardless new or old;

discovering the necessity of terminating the use of the existing progressive set of said data, and restarting a new progressive set of said data, on such conditions as, finding new earlier arrival propagation path, and/or finding said wireless transmitting device is moving;

discovering that previously discarded said data are actually of good quality, based on judgment using newly incoming said data, and recalling the discarded good quality data for use in said refining of the estimation of the location of said wireless transmitting device; and

discovering that previously kept said data are actually of poor quality, based on judgment using newly incoming said data, and discarding the kept poor quality data in said refining of the estimation of the location of the said wireless transmitting device.

9. The method of claim 8 further including a predetermined timer after said maximum data set size has reached, and every time a set of new good quality data is available and an equivalent amount of worst quality old data is excluded, the timer resets; if no additional good data is added at the time when said timer expires, the next incoming data, although probably being worse in quality than the worst in the existing set, will replace the worst in the existing set, the timer then resets and the process continues.

10. The method of claim 8 wherein the process for repeated measurements taking at a same position of said movable detection station, only keeping the best data obtained at the same said position, and eliminating worse data, regardless new or old, further subject to a predetermined timer that resets every time when better data replaces

worse, and if the timer expires, the next available and acceptable quality data replaces the too old good data.

11. The method of claim 1, when additional detection station(s) is available, further including a method of improving said determination of location of said wireless transmitting device, comprising additional steps of:

acquiring and receiving the transmitted signals from said wireless transmitting device also by said additional detection stations;

performing signal parameter measurements on said signals transmitted by said wireless transmitting device also by said additional detection station(s);

if any said additional detection station(s) is movable detection station(s), determining the location and orientation of said additional movable detection station(s) at each of said positions where said signal parameter measurements are performed;

sharing the resulting data of said signal parameter measurements obtained by said movable detection station and said additional detection station(s); also sharing the resulting data of said determined locations and orientations of said movable detection station and said additional movable detection station(s); and

performing and refining the estimation of the location of said wireless transmitting device using said shared data.

12. The method of claim 1, when said wireless transmitting device is communicating with at least one basestation of a wireless communication network, and when said movable detection station is also equipped with a basestation transmitter and receiver, referred to herein as movable detection-and-base station, further including a method of improving said determination of location of said wireless transmitting device, and

increasing the transmitting time duration for the said location determination supported by a battery of said wireless transmitting device, comprising the steps of:

obtaining the signal properties of the transmitted signals of said wireless transmitting device;

acquiring and receiving the transmitted signals from said wireless transmitting device by said movable detection-and-base station;

starting transmitting by said movable detection-and-base station after said movable detection-and-base station in question has detected that the received signal quality from said wireless transmitting device is higher than a predetermined threshold;

instructing said wireless transmitting device to hand off to said movable detection-and-base station;

controlling the transmitted signal properties of said wireless transmitting device;

performing signal parameter measurements at a plurality of positions of said movable detection-and-base station on the signals transmitted by said wireless transmitting device and received by said movable detection-and-base station, before and after said hand-off(s);

coordinating said control of the transmitted signal properties with activities of said signal parameter measurements;

determining the location and orientation of said movable detection-and-base station at each of said positions where said signal parameter measurements are performed; and

performing and refining estimation of the location of said wireless transmitting device.

13. The method of claim 1 wherein said determination of location can be improved and the battery supported transmitting time duration of said wireless transmitting device can be increased by further including the additional steps of:

controlling the transmitted signal properties of said wireless transmitting device; and

coordinating said control of the transmitted signal properties with activities of said signal parameter measurements.

14. The method recited in claim 13 wherein said transmitted signal properties are selected from at least one member of the group consisting of:

transmitted power;

transmitting duration;

transmitting duty cycle;

transmitted signal modulation method;

transmitted signal spreading method; and

transmitted signal frequency hopping method.

15. A method of determining the position of a target wireless transmitting device, and guiding the searching personnel(s) or searching robot(s) to physically reach said target wireless transmitting device, by making use of movable detection station(s) and movable reference wireless transmitting device(s), comprising the steps of:

determining the site (i.e., a localized area) where the target wireless transmitting device is located;

placing at least one said movable detection station(s) and at least one said movable reference wireless transmitting device(s) on site of or in the proximity of said target wireless transmitting device;

transmitting wireless signals from said at least one said movable reference wireless transmitting device(s);

obtaining the signal properties of the transmitted signals from said target wireless transmitting device and said movable reference wireless transmitting devices;

acquiring and receiving the transmitted signals from said target wireless transmitting device and said movable reference wireless transmitting device(s) by said movable detection station(s);

performing signal parameter measurements on the signals transmitted by said target and said reference wireless transmitting devices and received by said movable detection station(s);

determining the position and orientation of said movable detection station(s);

performing estimations of the positions of said target wireless transmitting device and said reference wireless transmitting device(s);

displaying on a displaying device the position of said target wireless transmitting device relative to the position(s) of said movable reference wireless transmitting device(s), and optionally also said movable detection station(s); and

moving said movable reference wireless transmitting device(s) so that the estimated and/or the displayed position of said reference wireless transmitting device relative to the estimated and/or displayed position of said target wireless transmitting device becomes closer, till said movable reference wireless transmitting device(s) physically reaches said target wireless transmitting device.

16. The method of claim 15 wherein said wireless signals transmitted from said movable reference wireless transmitting device(s) have same or similar radio propagation and

detectability properties as those of said signals transmitted from said target wireless transmitting device.

17. The same or similar radio propagation and detectability properties recited in claim 16, including:

same air interface technology;

same frequency;

frequency close to each other;

same bandwidth;

similar bandwidth;

same modulation;

similar modulation;

same frequency hopping properties;

similar frequency hopping properties;

same spreading properties;

similar spreading properties;

same transmitted power;

similar transmitted power;

same power control criterion;

similar power control criterion;

same transmitting duration;

similar transmitting duration;

same transmitting time slots; and

transmitting time slots close to each other in time.

18. The method of claim 15 further including a step of producing a quantitative measure to indicate how likely the reference and the target wireless transmitting devices are within the same physical land or construction structure (such as stairs), by comparing the similarity of characteristics of the signals transmitted by said target wireless transmitting device with those of the signals transmitted by said reference wireless transmitting device(s), and received by said movable detection station(s).

19. The characteristics of the signals transmitted by said target wireless transmitting device and said reference wireless transmitting device(s) recited in claim 18, comprising of:

the received signal strengths;

the reported transmitted power level; and

the multipath propagation profiles.

20. The method of claim 15 further including displaying of the traces of the movements of said reference wireless transmitting device(s) on said displaying device.

21. The method of claim 15 wherein said display of the relative positions of said target wireless transmitting device, said reference transmitting device(s) and said movable detection station(s) is shown on at least one displaying device(s) of:

a guiding device used by searching personnel(s);

a movable detection station;

a searching robot control station;

a public safety answering point;

a dispatch center; and

a command center.

22. The method of claim 21 when said guiding device is physically combined with said reference wireless transmitting device, or when said guiding device and said reference wireless transmitting device are carried by a same user, further including a method of an automatic image orientation adjustment of said display, so that the orientation of the displayed symbol of said target wireless transmitting device relative to the displayed symbol of said reference wireless transmitting device is always identical to the orientation of the actual physical position of said target wireless transmitting device relative to the user of said guiding device regardless the orientation change of said guiding device.

23. The automatic image orientation adjustment of said display recited in claim 22, comprising the steps of:

receiving the original image information that uses absolute direction such as north as orientation;

determining the physical orientation of said guiding device;

rotating said original image by the amount of the rotation of said determined orientation of guiding device from said absolute direction;

displaying the rotated image; and

continuously detecting the change of the orientation of said guiding device, and repeating above steps.

24. The method of claim 21 when said reference wireless transmitting device is installed on said searching robot, further including a method of an automatic image orientation adjustment of said display, so that the orientation of the displayed symbol of said target wireless transmitting device relative to the displayed symbol of said reference

wireless transmitting device is always identical to the orientation of the actual physical position of said target wireless transmitting device relative to the orientation of robot vision regardless the orientation change of said robot vision.

25. The automatic image orientation adjustment of said display recited in claim 24, comprising the steps of:

producing the original image information that uses absolute direction such as north as orientation;

determining the physical orientation of said robot vision;

rotating said original image by the amount of the rotation of said determined orientation of said robot vision from said absolute direction;

displaying the rotated image; and

continuously detecting the change of the orientation of said robot vision, and repeating above steps.

26. The method of claim 15 wherein said display of the positions of said target wireless transmitting device, said reference transmitting device(s) and said movable detection station(s) is overlaid on top of a pre-stored electronic map image of local area, and optionally further overlaid on top of a remote sensing photo of local land structures.

27. The method of claim 26 wherein said display further includes information about a third dimension along the height of positions of said target wireless transmitting device, said reference transmitting device(s) and said movable detection station(s).

28. The method of claim 15 wherein said estimation of the position of said target wireless transmitting device and said reference wireless transmitting device(s) includes transforming said measured signal parameters and said determined position and

orientation into at least one member of the following location estimation methods, consisting of:

a time and angle of arrival method in two dimensions; and

a time and angle of arrival method in three dimensions.

29. The method of claim 15 wherein said determination of positions and said guiding of search can be improved by further including the steps of:

determining the absolute positions of said movable detection station(s) and said movable reference wireless transmitting device(s) in at least two dimensions, using either a GPS based method (or alike) or an inertia based method or both; and

correcting said estimated relative positions using said determined absolute positions.

30. The method of claim 15 wherein said determination of positions and said guiding of search can be improved by further utilizing a plurality of said movable detection stations placed on site stationary at distinct positions, with following additional steps being performed:

determining the positions and orientations of each of said movable detection stations placed on site;

sharing said signal parameters measured by a plurality of said movable detection stations; and

performing said estimation of positions of said target and said reference wireless transmitting devices jointly using said shared measured parameters.

31. The method of claim 15 wherein said determination of positions and said guiding of search can be improved further by moving around at least one said movable detection station(s) in the close proximity of the site where the said target wireless transmitting

device is located, with the following additional steps being performed at a plurality of positions of said movable detection station(s):

performing said signal parameter measurement on the signals from said target and said reference wireless transmitting device(s);

determining the position and orientation of said moving movable detection station(s) at each of the positions where said signal parameter measurement are performed; and

performing and refining said estimation of positions of said target and said reference wireless transmitting devices using the said measured parameters obtained at said plurality of positions.

32. The method of claim 31 wherein said estimation of the positions of said target wireless transmitting device and said reference wireless transmitting device(s) includes transforming said measured signal parameters and said determined positions and orientations of said movable detection station(s) into at least one member of the group, consisting of:

an AOA (angle of arrival) method in two dimensions;

an AOA (angle of arrival) method in three dimensions;

a time and angle of arrival method in two dimensions;

a time and angle of arrival method in three dimensions;

a TOA (time of arrival) method in two dimensions;

a TOA (time of arrival) method in three dimensions;

a TDOA (time difference of arrival) method in two dimensions;

a TDOA (time difference of arrival) method in three dimensions;

a time difference and angle of arrival method in two dimensions; and

a time difference and angle of arrival method in three dimensions.

33. The method of claim 15 wherein said position determination and said guiding can be improved and the battery supported transmitting time duration of said target and/or reference wireless transmitting device(s) can be increased by further including:

controlling the transmitted signal properties of said target wireless transmitting device(s);

controlling the transmitted signal properties of said reference wireless transmitting device(s); and

coordinating said controls of the transmitted signal properties with activities of said signal parameter measurements.

34. The transmitted signal properties recited in claim 33 are selected from at least one member of the group consisting of:

transmitted power;

transmitting duration;

transmitting duty cycle;

transmitted signal modulation method;

transmitted signal spreading method; and

transmitted signal frequency hopping method.

35. The method of claim 15, when said target wireless transmitting device is communicating with at least one basestation in a wireless communication network, and when said movable detection station(s) is also equipped with a base station transmitter and receiver, referred to herein as movable detection-and-base station(s), further including a method of improving said position determination and said guiding,

and increasing the transmitting time duration for the said position determination and guiding supported by the batteries of said target and said reference wireless transmitting devices, comprising additional steps of:

starting transmitting by said movable detection-and-base station(s) after the movable detection-and-base station(s) in question has detected that the received signal quality from said target wireless transmitting device and/or said reference wireless transmitting device is higher than a predetermined threshold;

instructing said target wireless transmitting device to hand off to said movable detection-and-base station(s);

instructing said reference wireless transmitting device(s) to hand off to said movable detection-and-base station(s);

controlling the transmitted signal properties of the said target wireless transmitting device by said detection-and-base station(s);

controlling the transmitted signal properties of the said reference wireless transmitting device(s) by said detection-and-base station(s); and

coordinating said controls of the transmitted signal properties with activities of said signal parameter measurements.

36. The transmitted signal properties recited in claim 35 are selected from at least one member of the group consisting of:

transmitted power;

transmitting duration;

transmitting duty cycle;

transmitted signal modulation method;

transmitted signal spreading method; and

transmitted signal frequency hopping method.

37. A movable detection station for determining the location of a wireless transmitting device(s), and guiding the search for said wireless transmitting device(s), comprising:

a first antenna;

a first receiver, input from said first antenna, for receiving signals from said wireless transmitting device(s), and producing digitized baseband signals;

a second antenna;

a second receiver, input from said second antenna, for receiving signals from GPS satellites (or other similar systems), producing precise frequency reference and timing to said first receiver, and producing digitized GPS (or similar) information related to the location and orientation of the movable detection station in question;

a display and user interface unit, for presenting the location and guiding information to the user and accepting user control to the movable detection station in question; and

a digital signal processing unit, coupled to said first and second receivers, and to said display and user interface unit, performing signal parameter measurements on the signals provided by the first receiver, determining the location and orientation of said movable detection station in question, determining and refining the location estimation of said wireless transmitting device(s), accepting user controls through said display and user interface unit, producing information for display on said display and user interface unit, and controlling all the elements within the movable detection station.

38. The system of claim 37 wherein said first antenna is an array antenna, and said first receiver is an array receiver whose array channels are phase locked to each other.

39. The system of claim 38 wherein said array antenna can be configured to at least one member of group consisting of:

a one-dimensional array antenna, spanning over one of the three dimensions;

a two-dimensional array antenna, spanning over two of the three dimensions; and

a three-dimensional array antenna.

40. The system of claim 37 wherein said first antenna is a narrow beam antenna mounted onto a rotatable structure with an angle sensing means coupled to said digital signal processing unit.

41. The system of claim 37 further comprising of:

a third antenna, transmitting and/or receiving signals to/from a guiding device(s) used by searching personnel(s); and

a transceiver coupled to said third antenna and said digital signal processing unit, conveying information to said guiding device(s) for displaying on screen of said guiding device(s).

42. The system of claim 37, when used to determine the location of a wireless transmitting device(s) that communicates to a basestation in a wireless communication network, or guiding the search for such wireless transmitting device(s), further comprising of:

a forth antenna, for transmitting signals to said wireless transmitting device(s), or to a guiding device(s), or to a searching robot control station, or to all thereof;

a basestation transmitter, coupled to said forth antenna, also coupled to said digital signal processing unit, for enabling the basestation capabilities to said movable detection station, allowing said wireless transmitting device(s) to hand off to said movable detection station in question, and/or conveying information for display to said guiding device(s) used by searching personnel(s) or to said searching robot control station;

said first receiver further providing basestation receiver functionalities; and

said digital signal processing unit further providing basestation signal processing functionalities.

43. The system of claim 37 further comprising of:

a fifth antenna, transmitting signals for calibrating said first antenna and said first receiver, and when said wireless transmitting device(s) communicates with a basestation in a wireless communication network, also receiving signals from same basestation; and

a calibration transmitter and mobile receiver, coupled to said fifth antenna, also coupled to said digital signal processing unit, producing signals for calibrating said first antenna and first receiver, and when said wireless transmitting device communicates with a basestation in a wireless communication network, also receiving signals from same basestation that said wireless transmitting device is communicating with to obtain signaling messages and network timing, and passing them to said digital signal processing unit.

44. The system of claim 37 further comprising at least one member from the group consisting of:

a compass sensor, coupled to said signal processing unit, for determining the orientation of the structure of said first antenna in horizontal plane while said movable detection station stays stationary; and

a gravity sensor, coupled to said signal processing unit, for determining the orientation of the structure of said first antenna in vertical direction while said movable detection station stays stationary.

45. A guiding and reference device, used to work with a detection station to determine the position of a target wireless transmitting device and guiding the search for said target wireless transmitting device, comprising of:

a first antenna;

a reference transmitter, coupled to said first antenna, producing signals similar to what said target wireless transmitting device produces;

a second antenna;

a transceiver, coupled to said second antenna, receiving the position and guiding information from said detection station, and transmitting protocol signaling messages to said detection station;

a microprocessor, coupled to said reference transmitter and said transceiver, accepting and processing the position and guiding information received by said transceiver, configuring and controlling the functionalities of all the connected functional units within said guiding and reference device; and

a display and user interface unit, coupled to said microprocessor, accepting user controls for said guiding and reference device and passing them to said

microprocessor, and displaying to the user the position and guiding information that is received and processed by said microprocessor.

46. The guiding and reference device of claim 45 wherein said transceiver and said reference transmitter are combined, and said first and second antennas are combined.

47. The guiding and reference device of claim 45 further comprising:

a GPS antenna;

a GPS receiver, coupled to said GPS antenna and said microprocessor, receiving GPS signals (or signals from similar systems) for obtaining absolute position information, and passing said information to said microprocessor and then further transmitting to a detection station through said transceiver and said second antenna;

a compass sensor, coupled to said microprocessor, providing orientation information of said guiding and reference device for image rotation and displaying processing.

48. A searching robot that works with at least one movable detection station(s) to search for a target wireless transmitting device, comprising of:

a robot;

a reference wireless transmitting device, installed on said robot, transmitting wireless signals using radio properties same as or similar to what said target wireless transmitting device transmits, for assisting relative location estimation performed by said movable detection station(s); and

a compass sensor, installed on a vision subsystem of said robot, for detecting the orientation of said vision of said robot.